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SYNOPTIC PERFORMANCE CHARACTERISTICS OF THE
TWO-LEVEL ATMOSPHERIC MODEL

C. Schutz

RAND Corporation

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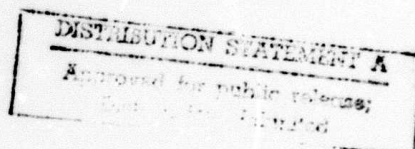
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A Report prepared for
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This analysis of the two-level atmospheric model compares daily changes during January from three experiments and five years of observed data for surface air temperatures at Columbia, Mo., and five basic characteristics in the vicinity of the Icelandic and Aleutian Lows. Strong diurnal changes were found in all simulated temperatures, but low and high diurnal ranges that would accompany specific synoptic events in nature are not well portrayed. The positions of the lows tested based on the lowest daily pressures were clumped, and in the North Atlantic were located southwest of the climatological center. Mean January pressures from these centers showed that the simulated Icelandic Low is 4.3 mb less intense, while the Aleutian Low is 1.9 mb more intense than observed. When all analyzed low pressure centers were combined, simulated speeds were slower and durations longer than observed. Finally, the simulated tracks were shown to be farther north. Refs.
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PREFACE

This report is concerned with the daily synoptic performance displayed by the Mintz-Arakawa two-level atmospheric general circulation model (GCM). Such presentations, which afford a comprehensive and nearly instantaneous picture of the state of the atmosphere at a given time each day, can help to identify peculiarities of the model, and may serve as a guide for future adjustments. Others working in the field may also find these results useful for comparison with their results.

This report is part of the work of the Rand/ARPA Climate Program, one of whose aims is the systematic comparison of model simulations with observed climate. Other Rand publications related by subject to the present report are R-1005-ARPA, which presents a systematic comparison of the observed climate with the January control integration used here, and a report on the performance of a revised version of the model for both January and July, which is in preparation.

These publications and the project of which they are a part are sponsored by the Defense Advanced Research Projects Agency.

SUMMARY

The present analysis of the Mintz-Arakawa model compares the synoptic characteristics of the simulated temperature and pressure in three January experiments with five years of observed January data. Tests are made of the average surface air temperature at the model grid point near Columbia, Missouri (CBI), and five basic characteristics of the circulation across the North Atlantic and North Pacific in the vicinity of the Icelandic and Aleutian Lows. Since these ocean regions are prime weather producers, the degree of agreement between their modeled and observed characteristics has global significance for the general circulation model (GCM).

While the model correctly simulates many observed features of the monthly average *large scale* surface air temperature, present analysis shows that the *local* mean January surface air temperatures at CBI are also in agreement with observation. However, further analysis of the daily and hourly simulated temperatures reveals some disagreement in the simulated diurnal pattern of warming and in the locally-simulated standard deviation of the temperature.

The characteristics of the North Atlantic (Icelandic) and North Pacific (Aleutian) Lows in January were judged from a comparison of Synoptic Weather Maps at 1230Z each day during 1949-1953, and those simulated daily by the numerical experiments at 0000Z. These maps served to identify the positions of all closed lows each day, the depth or intensity of the low at those positions, and the related speed, days of duration, and track of the lows based on changes in the daily positions. In the Atlantic, positions of the mean *lowest* pressures for January were southwest of the climatological center documented in Schutz and Gates (1971). The daily frequency distribution of the lowest pressures gives a mean depth 4.3 mb higher than that observed in the Atlantic, and 1.9 mb lower than that observed in the Pacific. This individual or synoptic characteristic of the low pressure centers is not evident when only the monthly average simulated pressure is examined.

The analysis of cyclone speed, duration, and track was based on the daily positions of *all* closed low pressure centers across the North

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Atlantic and North Pacific. It is shown that on the average the model has fewer centers and moves these cyclones at a slower speed than is observed. More cyclone speeds above 45 knots are observed than simulated, which may be the result of a more irregular movement in nature during cyclogenesis and cyclolysis. The analysis of cyclone duration shows that the cyclones were simulated to have slightly longer duration than is observed. The tracks of all cyclones used for the speed and duration calculations show that in both the North Atlantic and North Pacific, simulated tracks are farther north than those observed.

ACKNOWLEDGMENTS

Sincere appreciation is extended to the Environmental Technical Applications Center (ETAC) of the U.S. Air Force for its cooperation in making available the latest magnetic tapes of hourly synoptic weather reports at Columbia, Missouri. Thanks are also extended to Rand colleagues for their assistance: to W. L. Gates, who originally suggested the investigation, and who, along with R. R. Rapp and N. A. Hanunian, made a careful review of the manuscript and extended many valuable suggestions; to E. Rodriguez, who developed the programs necessary to interrogate the relevant weather data bank; and to C. R. Huber, D. S. Pass, R. L. Mobley, A. B. Nelson, and J. J. Simac, who produced the various maps and grid point data.

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1. INTRODUCTION

For our present purposes, only the temperature simulated by the model every six hours at the grid point near Columbia, Missouri (map designation CBI), and the daily changes in closed surface low pressures across the North Atlantic and North Pacific were used to examine the model's performance from a synoptic viewpoint during January. The model's performance over three separate January experiments has been selected for comparison. The January control experiment itself has been analyzed by Gates (1975).

Simulated data are presented in tables, graphs, and histograms for comparison with similar data observed in January of the years 1949-1953. Hourly observations at CBI each day during the five years were obtained on tape from the Environmental Technical Applications Center (ETAC). The daily series of Synoptic Weather Maps for 1949-1953 published by the U.S. Weather Bureau were used to determine daily changes in the five variables related to closed surface lows across the North Atlantic and North Pacific.

II. SURFACE AIR TEMPERATURE

The average daily surface air temperatures used for this analysis were extracted every six hours--0000-0600-1200-1800 local standard time (LST)--from the 31-day January simulations of three separate runs of the same control experiment; the runs differed only to the extent of small differences in their initial conditions. The air temperature computed by the atmospheric general circulation model (GCM) is described in Gates et al. (1971), and the model's climatological performance in the control integration has been summarized elsewhere (Gates, 1975). The average daily temperatures observed at Columbia, Missouri, were taken from the ETAC observations of hourly weather by the method described in Rodriguez and Huschke (1974).

From these temperature data (tabulated in the Appendix), the monthly mean maximum and minimum temperature, and the mean, range, and standard deviation of the daily averaged temperature were determined as shown in Table 1. The average daily and six-hourly variations of January 1950 surface air temperature were calculated as shown in Fig. 1. The observed mean and standard deviation from the combined 1949-1953

Table 1
TEMPERATURE (F°), COLUMBIA, MO., JANUARY
(Computed daily from 0000-0600 - 1200-1800
CST data)

	<u>Observed</u>					<u>Experiments</u>		
	<u>1949</u>	<u>1950^a</u>	<u>1951</u>	<u>1952</u>	<u>1953</u>	<u>1</u>	<u>2</u>	<u>3</u>
Maximum	58.0	58.3	53.0	58.3	54.0	43.5	47.6	44.9
Minimum	2.0	6.3	1.5	12.8	15.0	19.5	23.4	21.0
Range	56.0	52.0	51.5	45.5	39.0	24.0	24.2	23.9
Mean	27.9	31.9	30.2	33.7	33.6	32.8	34.6	35.2
Standard Deviation	12.5	13.4	13.3	12.5	8.1	5.2	5.9	5.5

^a Synoptically representative year.

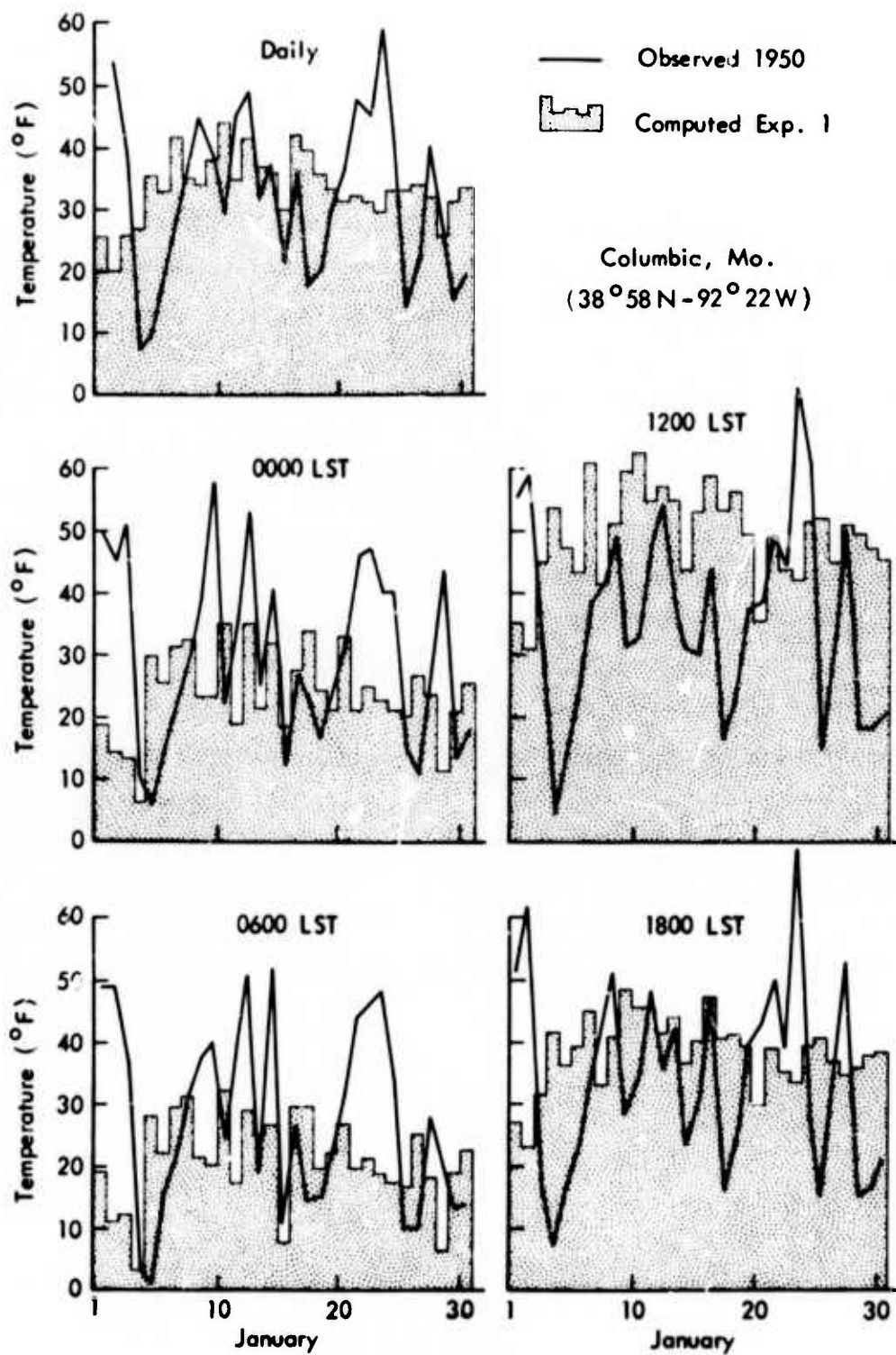


Fig. 1—Average daily and hourly variations of January surface air temperature, 1950, vs. Experiment 1

data indicate that 1950 is more synoptically representative in the sense that it most closely approximates mean conditions. In these 1950 data, marked excursions of daily mean temperature occur throughout the month, which are also reflected in the daily six-hour observations (see Fig. 1). In the *model*, while there is a strong diurnal change of all temperatures, the occurrence of the particularly low and high diurnal ranges that would accompany specific synoptic events is not well portrayed. Nevertheless, the simulated average surface air temperature is within 1°F of the mean for 1950 and equally close to that from approximately 30 years of recorded data (Schutz and Gates, 1971).

The histograms in Fig. 2 for all five years of observed data and for the three experiments show other differences. In general, the experiments' minimum temperatures are higher and their maximum temperatures are lower than those observed, while the experiments' standard deviation of 5.7°F is significantly less than the 12.3°F which occurred in nature for the years 1949-1953. Thus, although the model may adequately simulate the monthly average of such features as the surface air temperature, the local daily and hourly variations are such that there is a systematic underestimate of the observed variability.

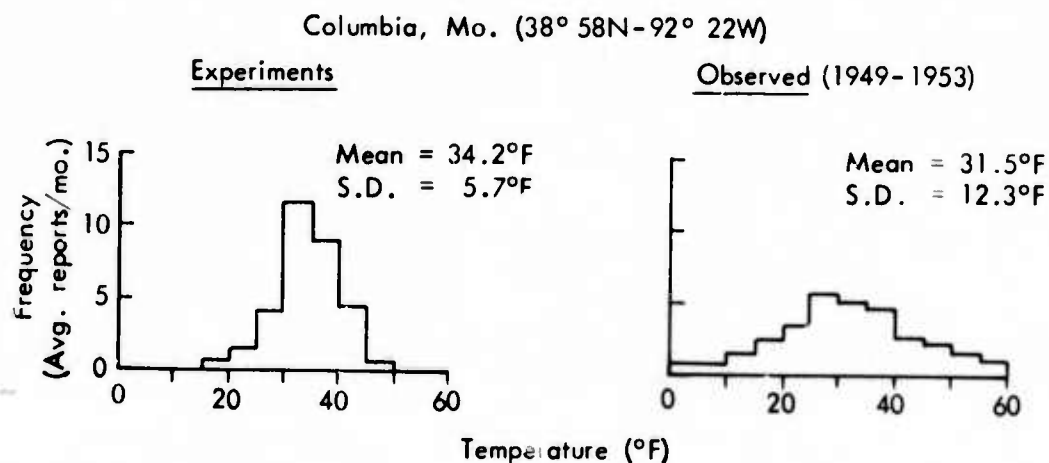


Fig. 2—Frequency distribution of daily surface air temperature (°F), January

III. SEA-LEVEL PRESSURE: ICELANDIC AND ALEUTIAN LOW CHARACTERISTICS

The mean climatological *position* and *intensity* of the Icelandic and Aleutian Lows are shown in Fig. 3, taken from Schutz and Gates (1971), and are based on approximately 30 years of January data. These centers are compared with the daily observed and simulated January values of the lowest pressures and their means. From synoptic data it is difficult to determine the position and intensity of the lowest daily pressure centers observed or simulated across the North Atlantic and North Pacific, due both to the inevitable errors of synoptic analysis and to the model's limited grid point resolution. The lowest daily simulated pressure at a grid point may not be the lowest implied pressure that could occur within the grid of 4° latitude and 5° longitude. Also, the "observed" lowest pressure depends on the analyst's interpretation of the available data; isobars may be added simply because of wind speed and direction at a single station some distance from the actual low center drawn. Therefore, no effort was made to adjust either the simulated grid point values or to consider interpolating observed values at the grid points used by the model.

POSITIONS

For the North Atlantic the mean January positions of the Icelandic Low based on *lowest* pressures for each test year and each experiment were obtained from the daily data in the Appendix, and are summarized in Table 2. The average pressure, standard deviation, and range for the years 1949-1953 again make 1950 appear synoptically representative, as was the case for surface air temperature at Columbia. Before averaging, the daily low positions from 1950 formed a distinct envelope of points around the mean climatological center from Schutz and Gates (1971) at 62°N-30°W (Fig. 4). Experiment 1, on the other hand, had a well-defined envelope of points southwest of the observed center. The mean January positions of the lowest Icelandic low pressure developed from each year's daily data and from the three January experiments fall into similar distinct groups (Fig. 5).

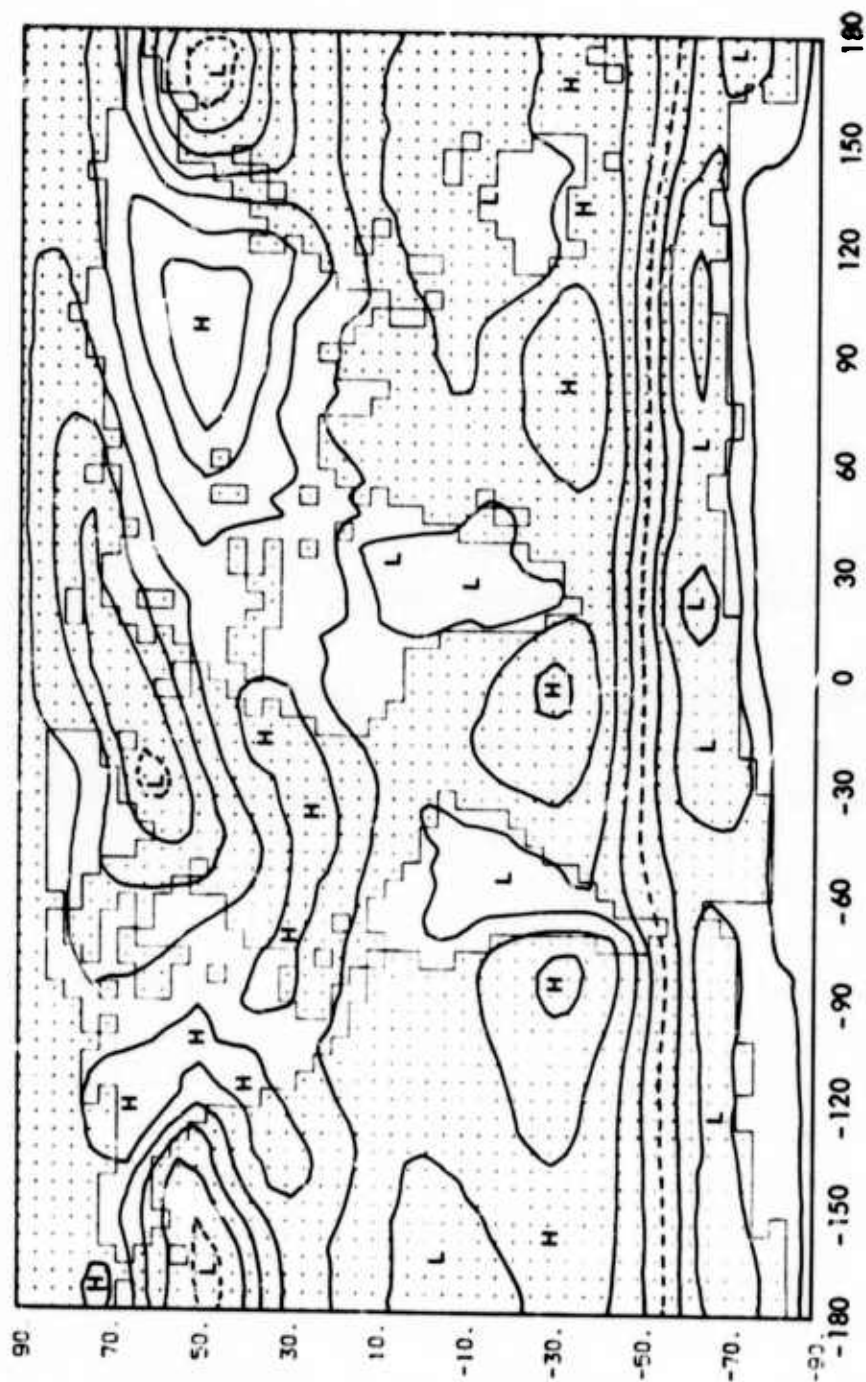


Fig. 3—Mean January sea-level pressure (mb). The analysis interval is 5 mb, and the 1000-mb isobar is dashed. Produced from data of Crutcher and Meserv (1970) and Taljaard et al. (1967).
From Schutz and Gates (1971).

Table 2

PRESSURE (mb) AND MEAN POSITION, JANUARY
(Based on daily lowest pressures)

		Icelandic Low				Experiments (0000Z)			
		Observed (1230Z)							
		1949	1950 ^a	1951	1952	1953	1	2	3
Mean Position {	Maximum	1000.0	1000.0	990.0	995.0	995.0	986.2	990.7	998.2
	Minimum	950.0	945.0	950.0	940.0	949.1	964.4	972.1	967.7
	Range	50.0	55.0	40.0	55.0	46.0	21.8	18.6	20.5
	Mean	970.1	973.5	971.2	970.4	977.5	975.2	979.5	975.7
	Standard Deviation	13.9	12.9	9.7	15.9	10.3	5.36	5.36	5.62
Latitude Longitude	Latitude	63.9N	60.0N	58.9N	63.3N	61.7N	52.6N	55.3N	53.9N
	Longitude	19.7W	32.7W	34.4W	24.5W	28.6W	40.8W	38.3W	45.0W
		Aleutian Low				Experiments (0000Z)			
		Observed (1230Z)							
		1949	1950	1951 ^a	1952	1953	1	2	3
Mean Position {	Maximum	998.3	1005.0	990.0	995.0	985.0	996.8	994.0	987.3
	Minimum	950.0	950.0	945.0	950.0	950.0	954.5	954.1	951.5
	Range	48.3	55.0	45.0	45.0	35.0	42.3	39.9	35.8
	Mean	975.9	982.2	973.8	973.5	968.6	973.95	974.2	971.2
	Standard Deviation	11.7	13.7	10.4	8.8	8.7	7.42	7.31	7.58
Latitude Longitude	Latitude	53.4N	46.0N	51.0N	53.2N	47.1N	53.3N	55.2N	55.4N
	Longitude	175.3E	165.0E	171.8W	167.0W	172.4W	173.4E	176.0E	174.4E

^a Synoptically representative year.

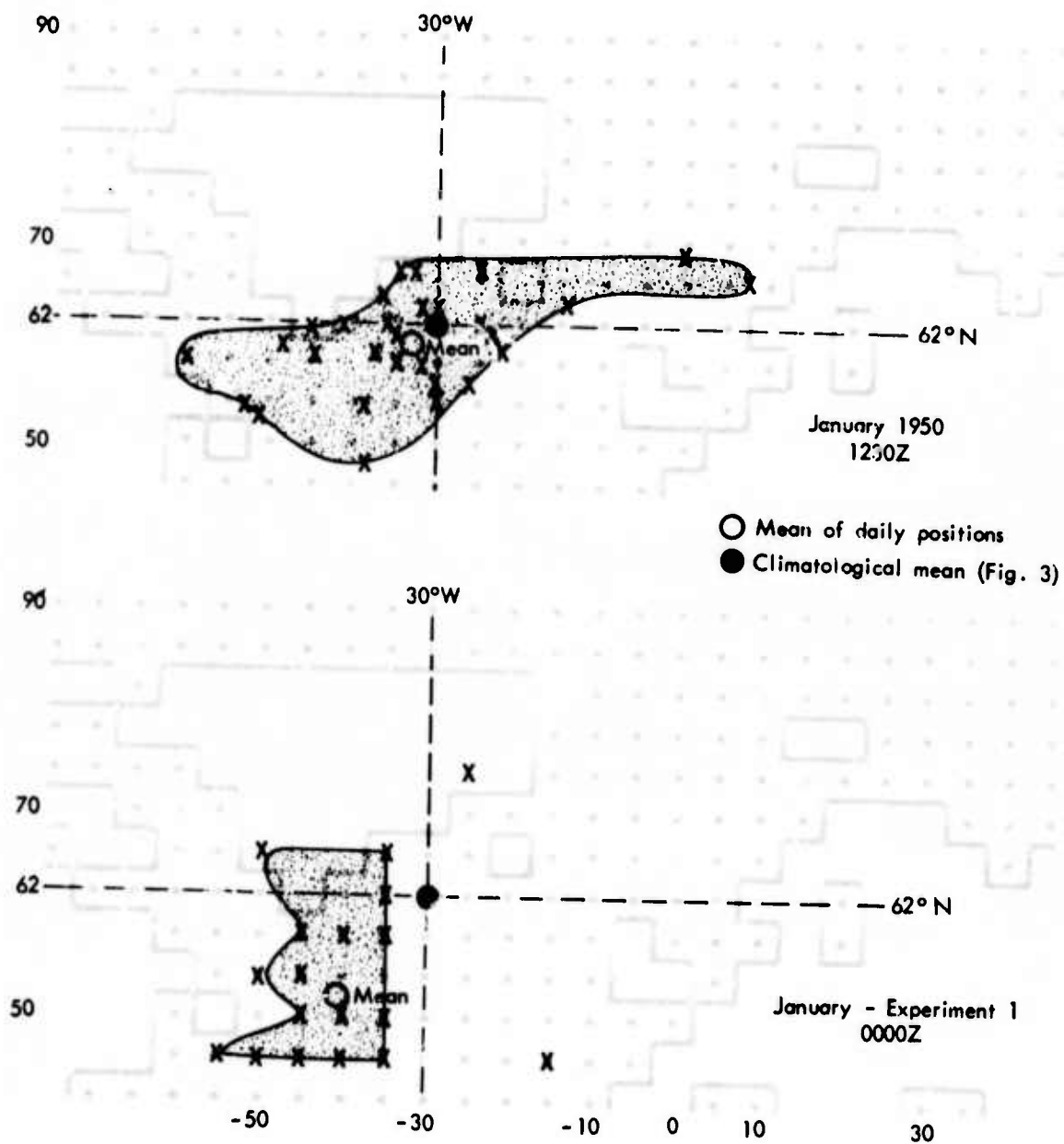
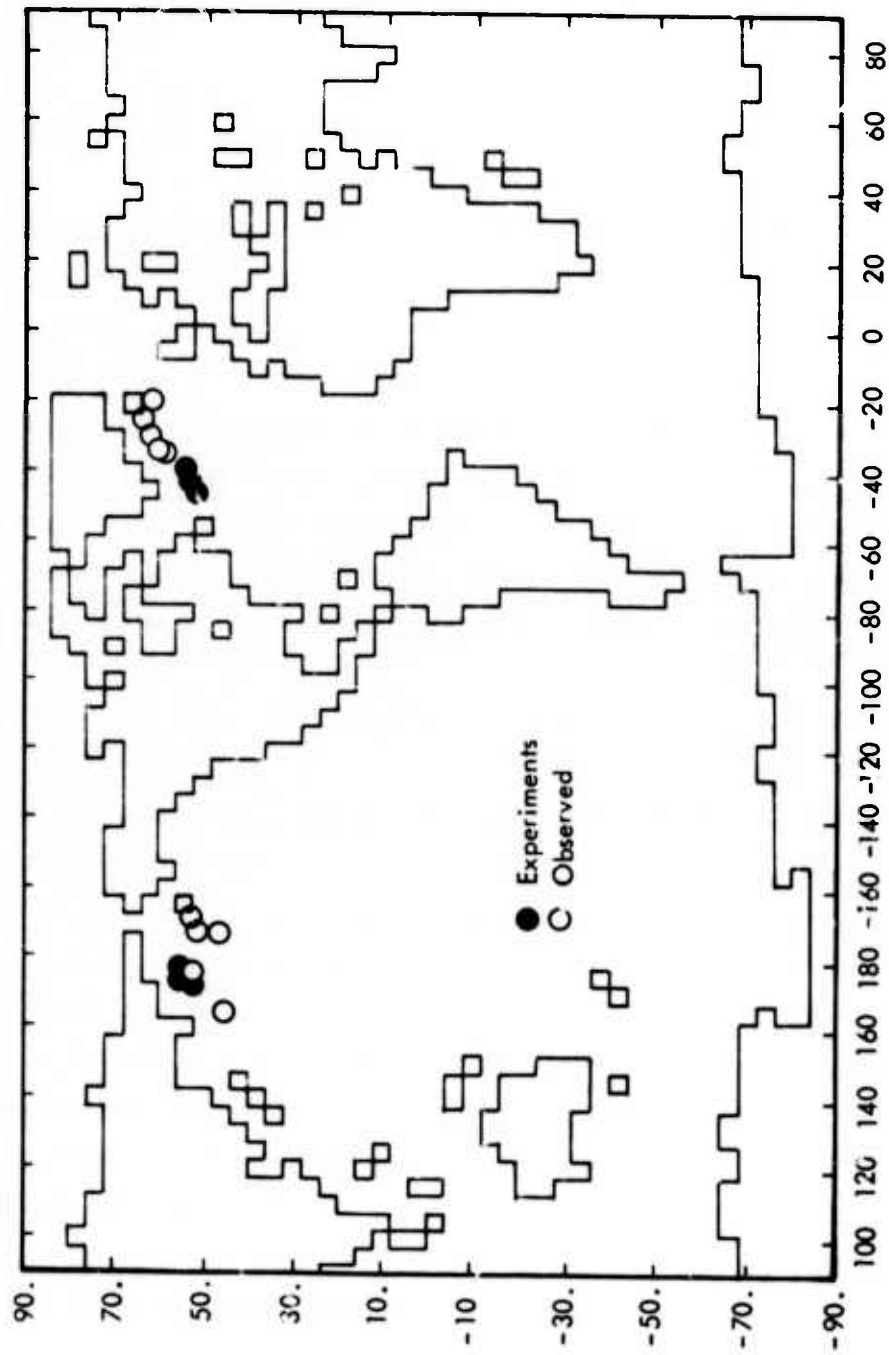


Fig. 4—Mean and daily positions of lowest pressure, Icelandic Low



Although the experiments indicate the Icelandic Low to be southwest of the mean climatological position, a check of Icelandic Low positions for Januaries from 1899-1960 reveals that only about 10 percent were observed in that locale (Bjerknes, unpublished). These anomalous observed positions of the Icelandic Low in January are generally near the positions simulated by the experiments.

The mean January positions of the Aleutian Low for each test year and each experiment were similarly determined from the daily data (see Appendix) and are also summarized in Table 2. The average pressure, standard deviation, and the range for the years 1949-1953 make 1951 the most synoptically representative of the test years. Before averaging, the daily positions from 1951 and from Experiment 1 each formed envelopes of points which covered the mean climatological center from Schutz and Gates (1971) at 50°N - 170°E (Fig. 6). When daily positions of the lowest pressure from all the experiments and test years are averaged and plotted, the resulting centers show good agreement (Fig. 5), even though the centers from the experiments are more tightly grouped.

INTENSITY

From the data in the Appendix, the highest and lowest of the lowest pressures, the range, mean, standard deviation (Table 2), and the daily variations of the lowest pressure were determined. Over the North Atlantic in the vicinity of the Icelandic Low the observed mean and standard deviation from the years 1949-1953 indicate that 1950 is synoptically representative of the intensity. The intensity range of the daily lowest pressures in 1950 was 55 mb, while in Experiment 1 it was 21.8 mb. The excursions of pressures within these ranges throughout January are shown in Fig. 7. In general, the simulated daily variations of pressure fall within the pattern established during January 1950. The histograms of the frequency distribution shown in Fig. 8 of intensity data show that within the range of lowest pressure the experiments give low pressures that are higher and high pressures that are lower than those observed. Druryan (1974) found that the GISS model also showed central pressures that were systematically too high in January. The frequency distribution of these daily January data for the North

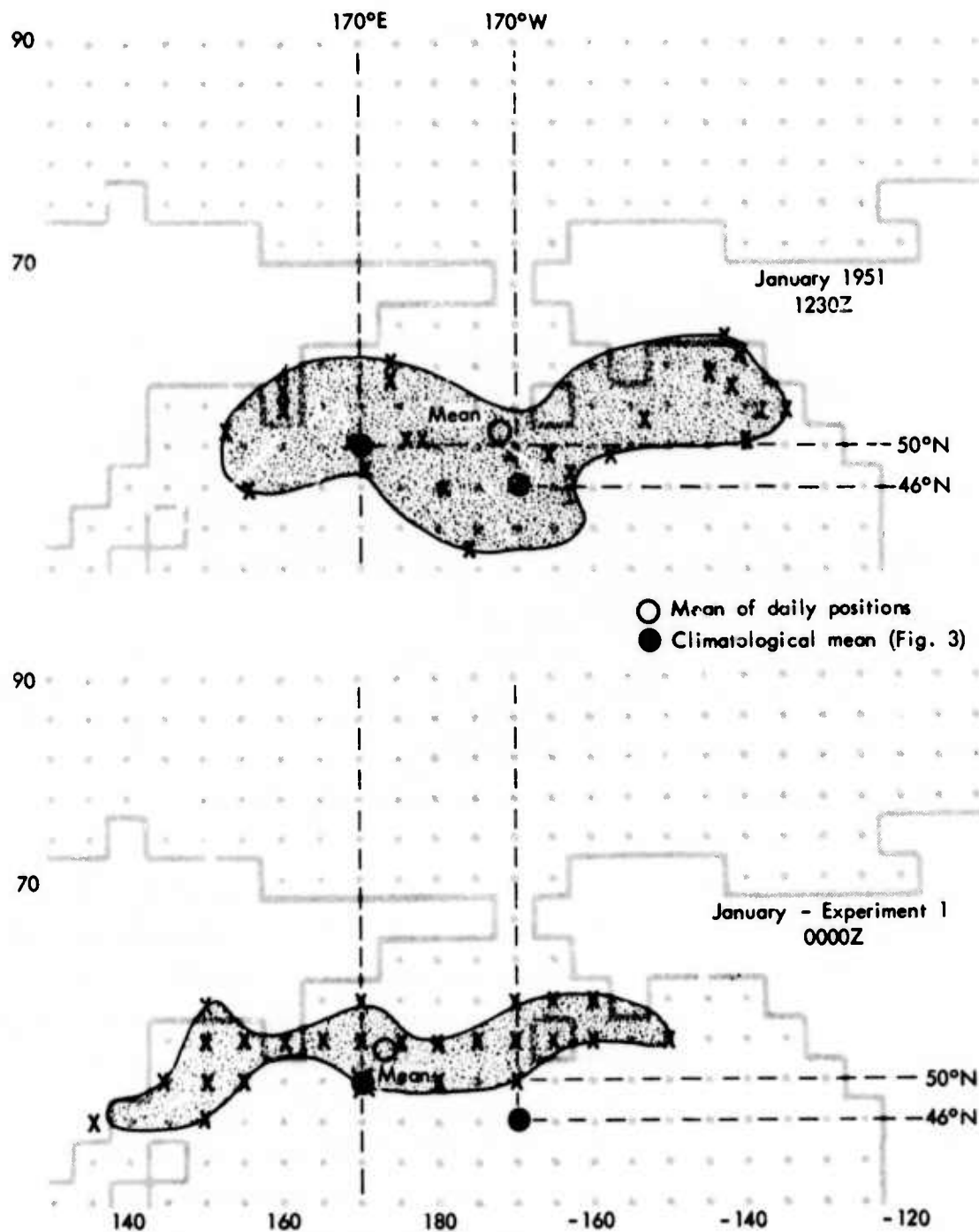


Fig. 6—Mean and daily positions of lowest pressure, Aleutian Low

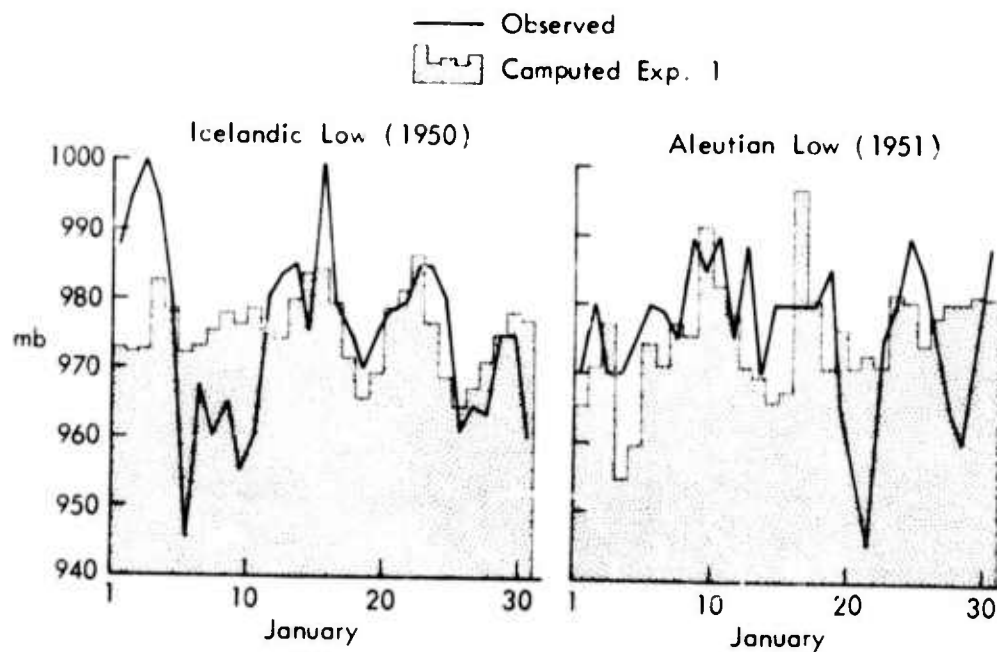


Fig. 7-- Daily variations of lowest pressure observed vs. Experiment 1, January

Atlantic indicates that the simulated pressures are also much less variable than those observed.

Over the North Pacific in the vicinity of the Aleutian Low, the observed mean and standard deviation from 1949-1953 indicate that 1951 is synoptically representative of the intensity. In 1951 the daily lowest pressure had a range of 45 mb, while in Experiment 1 the range was 42.3 mb. This similarity can be seen in the curve representing the plot of these daily data in Fig. 7. However, the histograms in Fig. 8, based on the frequency distribution of intensity data, show that within the range of lowest pressures, the experiments give low pressures that are higher and high pressures that are lower than those observed. As with the position data previously analyzed, there is better agreement between the experimental and observed intensity in the North Pacific than in the North Atlantic.

The difference in mean pressure shows that the simulated Icelandic Low is 4.3 mb less intense than is observed, while the simulated Aleutian

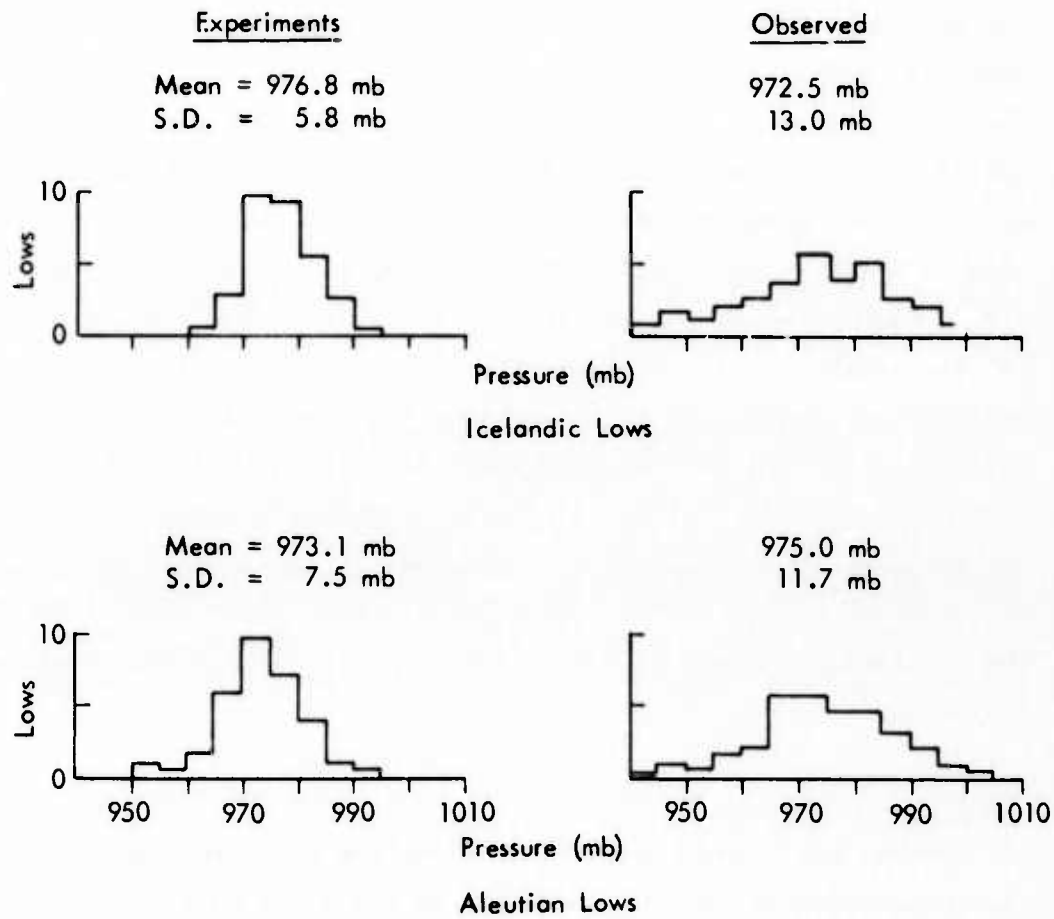


Fig. 8—Frequency distribution of combined intensities based on daily lowest surface pressures (mb), January

Low is 1.9 mb more intense than is observed on the average. When monthly means from the model are compared with long-term climatology, such as that from Schutz and Gates (1971), the model-simulated lows in Experiment 1 are 12-15 mb deeper than normal. This disagreement is due to the fact that the mean monthly pressure results from averaging the pressure for the month at each grid point without regard to the positions of individual lows. For example, if an exemplar grid point is chosen, then the average pressure there will take account of the occasional readings of relatively high pressure depending on the mobility of the low center. If the center is quite mobile, as was shown by the changing observed positions of the Icelandic Low in 1950 (Fig. 4), the selected grid point will experience many days of relatively high pressures, which implies a fairly high average pressure for the month; but if the low center hovers over and around the selected grid point, as in the case of Experiment 1 (Fig. 4), each day's reading will be low, from which it follows that the month's average value will be low. It can be recognized, therefore, that such an aggregate monthly statistic might make it appear that model results do not match their natural counterparts, while daily comparisons at the geographic centers of the individual lows could reveal a different result.

SPEED

Across the oceans, calculations for the mean and standard deviation of low center speeds were based on the daily positions of *all* "closed" low pressure centers, and not exclusively on the movements of the *lowest* pressure centers just discussed (Table 3). Also, only ocean points were used so that surface effects would be standard throughout the calculations. For both the North Atlantic and North Pacific, the calculation began when a low was at a land or ocean point nearest the western shore of the ocean. They were then continued across the ocean until cyclolysis occurred, or until an ocean or land point nearest the eastern shore of the ocean was reached. Although the calculation did not always begin at the time of cyclogenesis, there were instances where cyclogenesis and/or cyclolysis occurred over the ocean while the low was being tracked.

Table 3

SPEED (KNOTS), JANUARY
(Based on daily positions of
all pressure centers)

<u>Icelandic Low</u>								
	<u>Observed (1230Z)</u>					<u>Experiments (0000Z)</u>		
	<u>1949</u>	<u>1950</u>	<u>1951</u>	<u>1952</u>	<u>1953</u>	<u>1</u>	<u>2</u>	<u>3</u>
Mean	23.7	22.1	18.0	20.6	19.3	16.8	14.4	17.2
Standard Deviation	11.1	11.0	9.3	11.7	11.5	10.0	9.6	9.3

<u>Aleutian Low</u>								
	<u>Observed (1230Z)</u>					<u>Experiments (0000Z)</u>		
	<u>1949</u>	<u>1950</u>	<u>1951</u>	<u>1952</u>	<u>1953</u>	<u>1</u>	<u>2</u>	<u>3</u>
Mean	22.4	20.2	18.7	23.4	22.6	21.5	19.5	19.7
Standard Deviation	10.1	11.3	11.1	12.2	12.9	8.6	9.3	7.7

The frequency distribution of speed (knots) shown on the histograms (Fig. 9) is based on the distance a closed low moves each 24 hours. The distance between analyzed low centers from one map to the next is called a "period." Figure 9 indicates (1) that more periods were observed than were simulated and (2) that on the average the two-level model moves the lows slower than is observed. This same feature of model simulations has also been noted by Brown and Fawcett (1972) and Druyan (1974).

DURATION

Duration usually indicates the lifetime of a closed low center from cyclogenesis to cyclolysis. However, since these calculations were based on the same daily data used for the evaluation of speed, only data over the oceans were used and these did not always include a cyclone's complete cycle. In general, the experiments across both

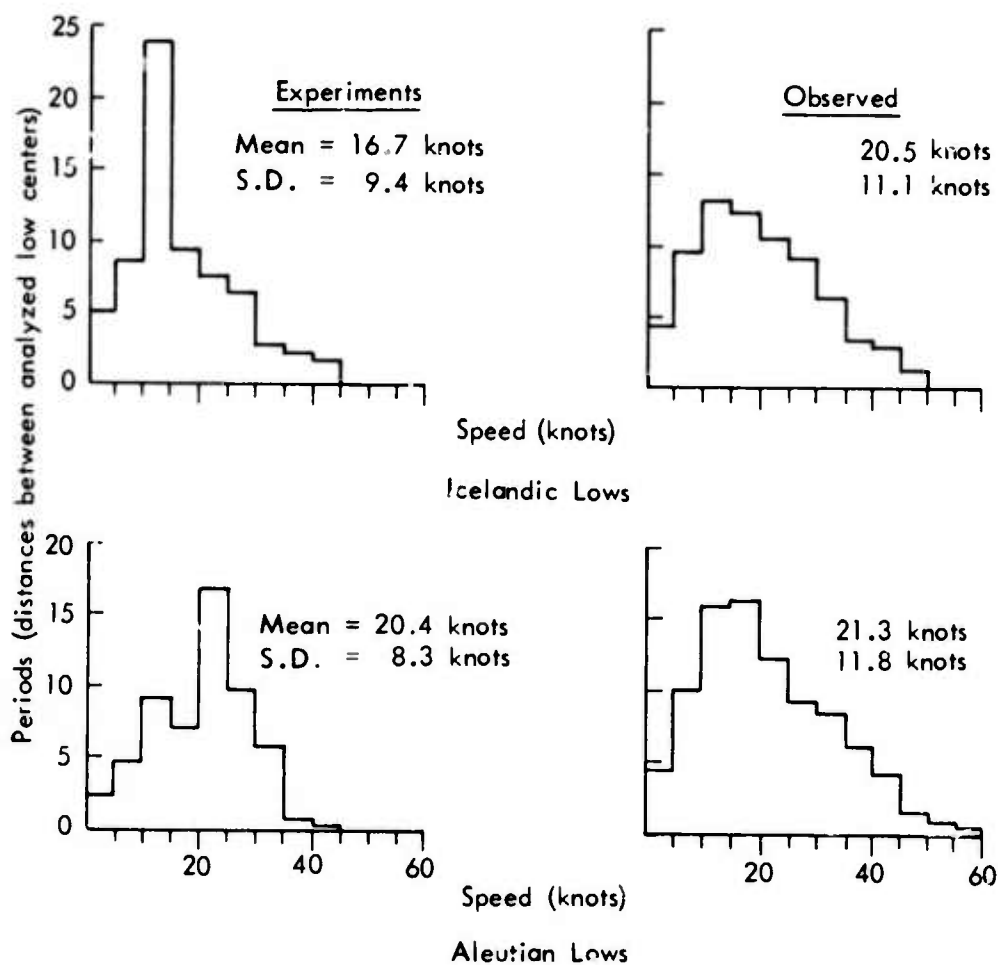


Fig. 9 — Frequency distribution of combined speed (knots) based on daily positions of all low pressure centers, January

oceans showed that the lows continued slightly longer than those observed; longer duration being, of course, consistent with their lower speed.

Over the North Atlantic and North Pacific, the mean and standard deviation of duration shown in Table 4 indicate good agreement during the individual years observed and the experiments. The frequency distribution of the combined data given in Fig. 10 shows that the observed means are lower; however, the standard deviations are higher in the Pacific and lower in the Atlantic than those simulated.

Table 4

DURATION (DAYS), JANUARY
(Based on daily positions of
all pressure centers)

<u>Icelandic Low</u>								
	<u>Observed (1230Z)</u>					<u>Experiments (0000Z)</u>		
	<u>1949</u>	<u>1950</u>	<u>1951</u>	<u>1952</u>	<u>1953</u>	<u>1</u>	<u>2</u>	<u>3</u>
Mean	3.5	3.2	3.8	3.2	4.9	4.9	3.9	4.2
Standard Deviation	1.0	1.4	1.8	1.8	3.2	4.0	2.9	2.9

<u>Aleutian Low</u>								
	<u>Observed (1230Z)</u>					<u>Experiments (0000Z)</u>		
	<u>1949</u>	<u>1950</u>	<u>1951</u>	<u>1952</u>	<u>1953</u>	<u>1</u>	<u>2</u>	<u>3</u>
Mean	3.8	4.3	3.3	4.5	4.0	5.5	4.4	3.9
Standard Deviation	3.2	2.2	2.4	2.6	3.0	1.6	2.5	2.3

TRACKS

The mean tracks or paths of *all* closed low centers shown in Fig. 11 were a by-product of the speed and duration calculations. They are presented to provide further insight into the differences between simulated and observed conditions. In both the North Atlantic and North Pacific, the simulated tracks of low-pressure centers are generally

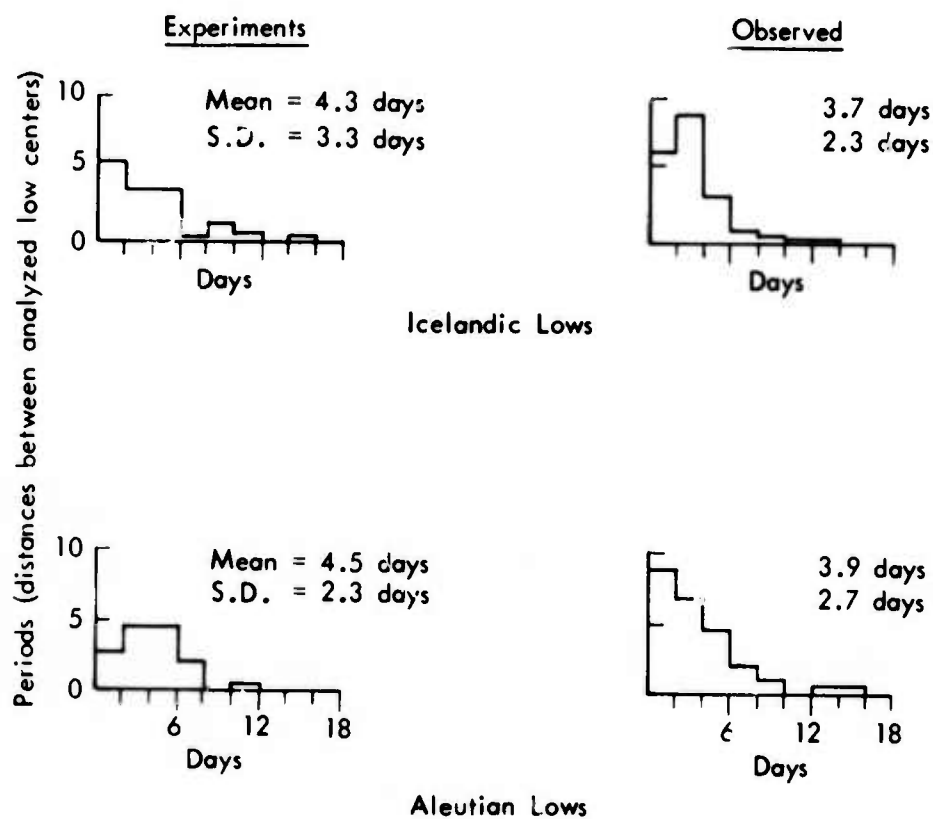


Fig. 10—Frequency distribution of combined duration (days) based on daily position of all low pressure centers, January

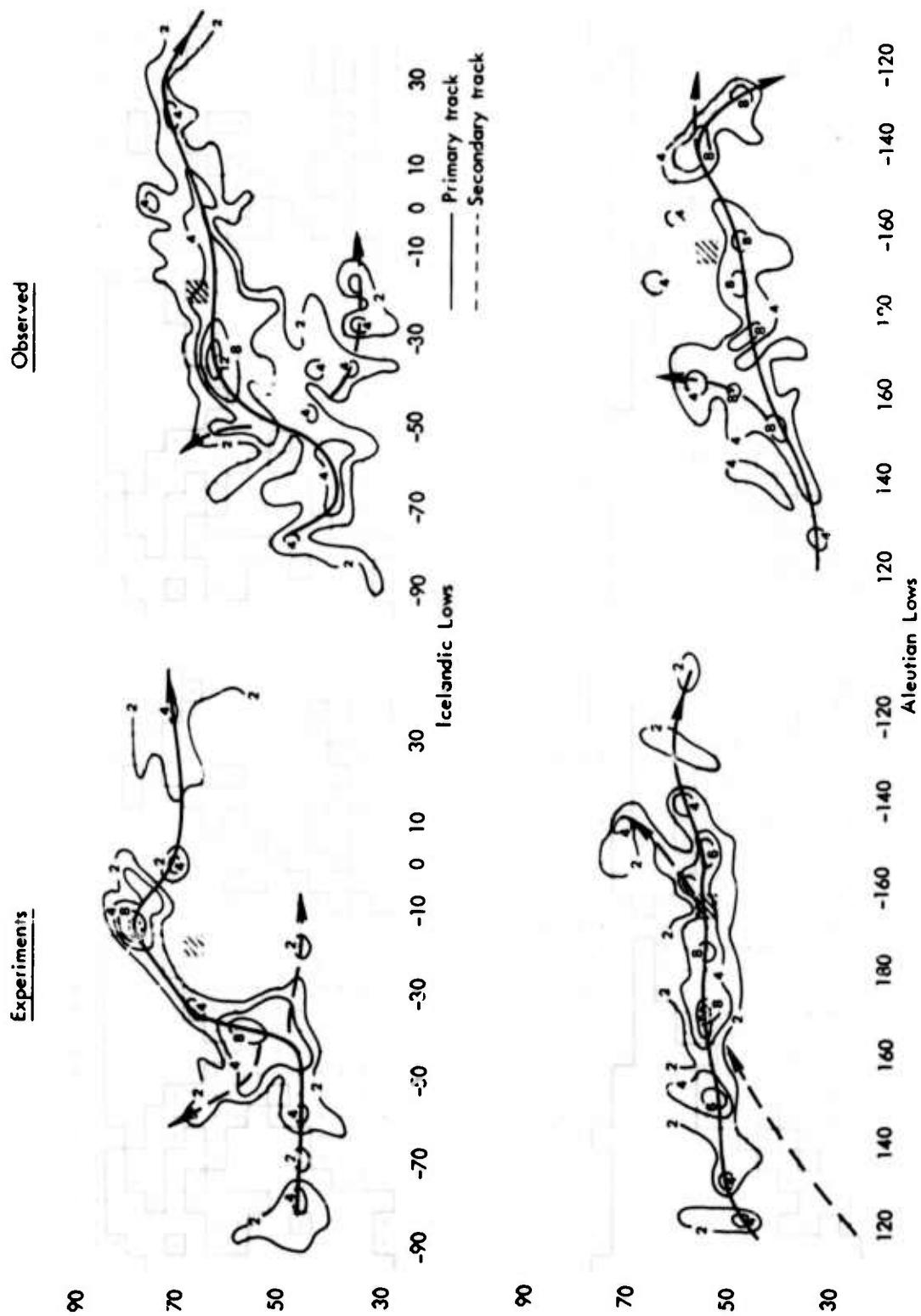


Fig. 11—Combined low tracks on all closed low centers (not on lowest pressure centers alone)

north of those observed, as may be seen by referring to the cross-hatched grid square representing Iceland and the Aleutians. This is true not only for the primary track (solid line), but for the secondary track (dashed line) as well. A second important difference between the simulations and observation is the more random distribution of the individual tracks in the observed data. This is shown by the plotted numbers at each grid point representing the number of times a low passed near that grid point at map time. The track characteristics in Fig. 11 were determined by subjectively connecting the locations of the maximum number of such passages. The basic tracks developed by this procedure did not always go through either the mean center of lowest pressure (Fig. 5), or the latitude and longitude of the single lowest pressure for January. A summary of all low-pressure center tracks used indicates that more low "positions" are observed than are simulated, as shown in Table 5.

Table 5

LOW TRACKS, JANUARY

(Based on daily positions of
all pressure centers)

<u>North Atlantic</u>								
<u>Observed (1230Z)</u>					<u>Experiments (0000Z)</u>			
<u>1949</u>	<u>1950</u>	<u>1951</u>	<u>1952</u>	<u>1953</u>	<u>1</u>	<u>2</u>	<u>3</u>	
Tracks	15	25	21	20	20	14	16	17

<u>North Pacific</u>								
<u>Observed (1230Z)</u>					<u>Experiments (0000Z)</u>			
<u>1949</u>	<u>1950</u>	<u>1951</u>	<u>1952</u>	<u>1953</u>	<u>1</u>	<u>2</u>	<u>3</u>	
Tracks	16	24	29	20	25	11	13	13

IV. CONCLUSIONS

It has been shown that daily variations of surface-air temperature and five synoptic variables related to closed low-pressure centers give additional insight to model behavior when compared with representative observed data. The principal findings are:

1. Large diurnal variations of surface air temperature are simulated between 0600LST to 1200 LST at Columbia, Missouri, and these are systematically larger than those observed.
2. When daily surface pressure is used at fixed geographical points to determine the mean monthly pressure, the simulated Icelandic Low is less intense than observed, while the Aleutian Low is more intense than observed, as compared with the lowest reported pressure each day.
3. The simulated speeds of all low-pressure centers, including those with the lowest pressure, are systematically slower than the observed speeds.
4. Both the simulated daily and mean January positions of the Icelandic low-pressure center tend to occur southwest of the observed climatological center. There is better agreement, however, when comparing positions in the vicinity of the Aleutian Low.

It is hoped that future improvements of the model will reduce these errors in synoptic performance, even though the model is not intended to be used in short-range forecasting. In view of the systematic character of many of these errors, however, there is a possibility that they may affect the model's simulation of climatic statistics at time ranges well beyond the model's acknowledged predictability limit.

APPENDIX
DATA TABULATIONS

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Table A-1

AVERAGE DAILY SURFACE AIR TEMPERATURE (°F), JANUARY

(Computed daily from 0000-0600 - 1200-1800 CST data)

		Observed					Simulated			
Day \ Yr	1949	1950	1951	1952	1953	Avg.	Day \ Yr	1	2	3
1	23.	51.3	44.0	21.8	34.0	34.8	371	24.9	25.7	26.1
2	37.	53.8	45.0	17.8	34.0	37.5	372	19.5	27.1	27.0
3	45.	33.5	27.3	23.0	27.5	31.3	373	25.3	35.6	36.4
4	39.	6.3	27.3	29.5	27.5	25.9	374	26.1	31.9	30.2
5	26.	9.3	34.5	25.3	27.8	24.6	375	35.3	46.1	43.4
6	34.	19.5	21.8	23.5	27.0	25.2	376	32.2	37.4	38.1
7	44.	28.5	17.0	29.3	21.8	28.1	377	41.4	36.1	29.3
8	51.	36.0	22.0	39.0	26.0	34.8	378	34.2	37.8	33.9
9	35.	44.0	38.8	29.0	32.3	35.8	379	33.6	42.9	43.0
10	27.	39.3	36.8	22.0	29.8	30.9	380	37.7	36.4	39.3
11	31.	28.3	31.0	32.8	30.8	30.8	381	43.5	38.1	43.5
12	28.	42.5	40.0	39.3	45.8	39.1	382	34.0	30.2	33.6
13	30.	48.3	41.8	48.0	50.8	43.8	383	40.5	32.4	35.8
14	38.	31.0	37.0	58.3	54.0	43.7	384	36.0	31.2	41.2
15	58.	36.8	34.5	46.3	41.5	43.4	385	34.6	34.4	36.5
16	31.	20.8	40.3	56.8	15.0	32.8	386	29.6	35.3	31.6
17	17.	36.3	53.0	56.3	25.3	37.6	387	40.9	30.7	37.9
18	25.	17.3	49.0	39.5	31.0	32.4	388	39.1	34.0	37.4
19	14.	19.5	49.3	52.5	32.3	33.5	389	35.0	31.0	36.8
20	13.	29.5	29.5	32.8	32.3	27.4	390	32.6	33.3	35.7
21	29.	35.5	16.8	32.8	33.3	29.5	391	31.1	37.7	36.7
22	24.	47.0	30.3	26.8	37.3	33.1	392	31.8	44.1	31.4
23	36.	44.3	35.8	13.0	34.5	32.7	393	30.9	39.3	21.0
24	29.	58.3	23.5	21.8	29.5	32.4	394	29.1	30.3	34.3
25	17.	41.0	22.0	46.5	30.5	31.4	395	32.3	40.4	44.9
26	22.	13.5	38.5	40.5	41.5	31.2	396	32.3	47.6	41.1
27	28.	21.3	29.5	34.3	37.3	30.1	397	33.2	38.3	37.7
28	15.	39.8	9.8	23.8	30.0	23.7	398	31.4	32.7	32.5
29	2.	24.3	1.5	12.8	35.5	15.2	399	25.5	24.9	33.8
30	3.	15.0	3.5	27.55	46.3	19.1	400	30.9	23.4	26.4
31	14.	18.3	5.5	42.3	37.8	23.6	401	32.4	26.6	35.0
Range	56.0	52.0	51.5	45.5	39.0	28.6		24.0	24.2	23.9
Mean	27.9	31.9	30.2	33.7	33.6	31.5		32.8	34.6	35.2
Standard Deviation	12.5	13.4	13.3	12.5	8.1	12.3		5.2	5.9	5.5

Table A-2

OBSERVED HOURLY SURFACE AIR TEMPERATURES (°F), COLUMBIA, MO. (3858N-9222W)

January 1950

Day	Hr	0000LST	0600LST	1200LST	1800LST	Avg
1		50	49	55	51	51.3
2		45	49	59	62	53.8
3		51	37	29	17	33.5
4		11	3	4	7	6.3
5		6	1	14	16	9.3
6		16	16	24	22	19.5
7		22	21	38	33	28.5
8		29	31	41	43	36.0
9		39	37	49	51	44.0
10		58	40	31	28	39.3
11		22	24	33	34	28.3
12		35	39	48	48	42.5
13		53	51	54	35	48.3
14		25	19	38	42	31.0
15		41	52	31	23	36.8
16		12	11	30	30	20.8
17		27	27	44	47	36.3
18		23	14	16	16	17.3
19		16	15	23	24	19.5
20		22	20	37	39	29.5
21		31	31	38	42	35.5
22		46	44	49	49	47.0
23		47	46	45	39	44.3
24		40	48	73	72	58.3
25		40	35	62	27	41.0
26		15	10	14	15	13.5
27		11	10	31	33	21.3
28		28	28	50	53	39.8
29		44	20	18	15	24.3
30		15	13	18	16	15.0
31		18	14	20	21	18.3
						31.9 TOTAL

Table A-3

SIMULATED HOURLY SURFACE AIR TEMPERATURE (°F), COLUMBIA, MO. (GRID POINT)

Experiment #1

Day	Hr	0000LST	0600LST	1200LST	1800LST	Avg
371		18.81	19.01	35.12	26.66	24.90
372		13.78	10.80	30.61	22.91	19.53
373		13.42	11.88	44.46	31.56	25.33
374		5.95	2.92	53.61	41.71	26.05
375		29.90	28.00	47.27	35.95	35.28
376		25.41	21.91	43.05	38.43	32.20
377		31.28	29.50	60.48	44.50	41.44
378		32.05	30.79	41.74	32.25	34.21
379		22.67	21.15	50.39	40.22	33.61
380		22.66	20.25	59.73	48.10	37.69
381		34.80	31.98	62.06	45.33	43.54
382		18.42	17.50	54.28	45.61	33.95
383		35.02	28.84	56.85	41.09	40.45
384		21.16	24.82	54.11	44.05	36.04
385		31.92	26.49	43.65	36.21	34.57
386		18.12	7.39	52.74	39.95	29.55
387		27.63	29.75	58.70	47.43	40.88
388		33.67	29.74	52.85	40.21	39.12
389		24.03	19.58	55.96	40.52	35.02
390		20.49	22.01	48.83	39.20	32.63
391		32.54	26.55	35.40	29.88	31.09
392		20.40	19.77	48.48	38.37	31.75
393		24.30	20.89	43.80	34.80	30.95
394		22.25	18.50	41.90	33.57	29.08
395		21.22	17.31	51.60	39.26	32.35
396		20.34	16.90	51.77	40.06	32.27
397		26.65	25.04	44.56	36.60	33.21
398		23.52	17.94	50.13	34.18	31.44
399		11.39	6.11	49.01	35.47	25.50
400		20.38	19.18	46.46	37.47	30.87
401		24.95	22.21	44.49	38.05	32.43
						32.8 TOTAL

POSITION AND INTENSITY OF LOWEST PRESSURE CENTER DAILY ACROSS NORTH ATLANTIC, JANUARY

YR	1230Z										0000Z					
	1949		1950		1951		1952		1953		EXP. 1		EXP. 2		EXP. 3	
Day	Lat Lon	Press mb	Lat Lon	Press mb	Lat Lon	Press mb	Lat Lon	Press mb	Lat Lon	Press mb	Lat Lon	Press mb	Lat Lon	Press mb	Lat Lon	Press mb
1	53-7	955.0	63-30	987.7	54-6	980.0	61-28	995.0	40-64	985.0	50-35	972.9	50-35	973.4	50-35	973.5
2	63+5	960.0	66+9	995.0	55-39	980.0	66+8	983.6	41-53	985.0	50-40	972.3	54-40	973.2	50-40	977.7
3	71+13	965.0	56-26	1000.0	56-27	980.0	61-38	970.0	41-70	990.0	58-40	972.7	58-40	973.0	58-40	974.0
4	64+5	985.0	60-22	994.4	57-19	980.0	65-37	975.0	67-17	984.0	58-40	982.8	58-40	983.1	58-45	983.5
5	65-19	975.3	61-23	980.0	51-56	977.5	65-25	940.0	73+5	985.0	54-50	978.2	54-50	978.9	54-50	976.3
6	71-0	970.0	56-30	945.0	58-45	960.0	75-20	944.8	59-53	985.0	54-45	972.1	58-45	973.6	54-45	970.6
7	59-10	1000.0	55-30	967.7	60-43	973.2	68-26	960.0	73+25	993.7	58-45	973.3	58-45	976.5	58-45	974.1
8	55-54	990.0	58-32	960.0	67-50	984.1	67-9	945.0	57-39	985.0	66-50	975.3	66-30	981.4	66-35	975.2
9	67-43	975.0	58-35	965.0	54-49	970.0	60-1	950.0	57-42	975.0	74-25	977.9	74-25	972.1	74-30	971.6
10	73+10	950.0	51-32	955.0	60-34	950.0	66+5	959.6	64-31	988.0	50-40	976.1	50-40	974.1	50-40	972.4
11	61-53	995.0	60-22	960.0	60-15	965.0	60+2	968.8	67-22	981.0	46-55	978.5	58-40	976.9	58-40	976.9
12	64-32	980.0	69-0	980.0	60-4	967.9	58-40	970.0	61-61	980.0	50-40	975.8	50-45	975.1	50-50	972.5
13	65-32	975.0	64-15	983.4	61-28	975.0	66-25	948.0	65-55	975.0	58-35	974.2	54-40	975.8	54-40	971.1
14	74+17	960.0	62-25	985.0	47-45	975.0	68-3	970.0	65-30	985.0	62-35	979.9	58-35	982.6	54-40	975.4
15	64-30	972.1	54-54	975.0	50-41	960.0	62+5	955.0	70-25	982.2	66-35	983.5	62-35	984.6	62-40	983.2
16	66-5	975.0	48-39	1000.0	59-35	975.0	69+6	975.0	75+10	970.0	50-45	984.1	66-35	987.6	66-35	988.2
17	67-7	950.0	64-37	980.0	66-14	969.0	67+5	984.2	53-53	970.0	54-45	979.6	58-55	984.3	46-5	977.1
18	65-25	970.0	59-45	975.0	54-46	995.0	55-43	980.0	59-45	990.0	46-45	971.3	62-55	978.9	50-45	967.7
19	68-6	950.0	53-53	970.0	45-38	990.0	53-60	972.8	70-10	990.0	54-45	965.5	50-40	984.9	58-50	967.7
20	68-3	950.0	62-37	975.0	59-35	975.0	60-54	980.0	72+25	965.7	54-50	969.8	54-45	975.8	42-50	973.8
21	63-38	985.0	61-45	978.3	62-37	980.0	50-62	993.2	72-60	995.0	50-45	978.9	58-50	976.1	46-45	968.2
22	65-25	974.3	67-25	979.6	57-55	975.0	57-60	975.0	62-40	985.0	46-35	981.4	58-45	973.9	54-50	972.0
23	71-20	970.0	67-35	984.9	64-43	970.0	64-68	992.7	44-50	985.0	46-40	986.2	58-55	974.5	58-55	976.2
24	75-20	972.8	60-49	985.0	66-30	975.0	71+15	985.0	57-37	970.0	46-50	976.4	50-35	984.3	58-60	986.2
25	64-38	955.0	67-34	980.0	64-35	980.0	67+5	985.7	63-41	949.1	46-50	969.1	46-30	986.4	50-35	986.2
26	76-0	960.0	63-32	960.9	62-27	984.0	63-51	985.8	65-32	965.0	46-45	964.4	46-25	985.8	54-40	983.2
27	66-30	975.0	54-39	965.0	71-10	980.0	64-35	990.1	64-35	965.0	46-35	967.7	50-25	984.1	46-70	978.8
28	41-40	989.0	61-35	963.6	60-45	955.0	51-36	990.0	69+13	965.0	50-35	971.6	46-20	984.4	46-55	968.4
29	39-39	985.0	62-41	975.0	61-37	965.0	64-39	975.0	69+12	971.0	46-15	974.7	46-20	985.3	46-50	971.6
30	59-55	985.0	59-61	975.0	64-35	965.0	65-35	960.8	61-14	990.0	50-35	978.0	50-30	990.7	46-45	974.5
31	60-50	984.4	59-38	960.0	62-41	965.0	64-10	966.7	56+4	975.0	46-40	977.4	-	-	-	-
Range	950.0-1000.0		945.0-1000.0		950.0-990.0		940.0-995.0		949.1-995.0		964.4-986.2		972.1-990.7		967.7-988.2	
Mean	970.1		973.5		971.2		970.4		977.5		975.2		979.5		975.7	
Standard Deviation	13.9		12.9		9.7		15.9		10.3		5.36		5.56		5.62	
Mean Lat	63.9N		60.0N		58.9N		63.3N		61.7N		52.6N		55.3N		55.9N	
Mean Lon	19.7W		32.7W		34.4W		24.5W		28.6W		40.8W		38.3W		45.0W	

*Lat = Latitude, Lon = Longitude, (minus = west).

Table A-5

POSITION AND INTENSITY OF LOWEST PRESSURE CENTER DAILY ACROSS NORTH PACIFIC, JANUARY

YR	12302										00002					
	1949		1950		1951		1952		1953		EXP. 1		EXP. 2		EXP. 3	
	Lat ^a Lon	Press mb	Lat Lon	Press mb	Lat Lon	Press mb	Lat Lon	Press mb	Lat Lon	Press mb	Lat Lon	Press mb	Lat Lon	Press mb	Lat Lon	Press mb
1	43 ₁₇₆	995.0	56 ₁₅₉	990.0	45 ₁₅₅	970.0	48 ₁₆₃	985.0	59 ₁₅₃	979.9	54 ₁₇₅	965.6	54 ₁₇₅	966.3	54 ₁₈₀	966.4
2	52 ₁₆₅	980.0	57 ₁₇₇	995.0	44 ₁₇₂	980.0	58 ₁₇₅	985.0	42 ₁₆₄	975.0	58 ₁₇₀	971.1	58 ₁₇₀	971.9	58 ₁₇₀	970.3
3	58 ₁₅₃	969.0	49 ₁₅₇	990.0	50 ₁₆₉	970.0	62 ₁₆₅	975.0	42 ₁₆₀	965.0	50 ₁₄₅	977.6	50 ₁₄₅	979.6	50 ₁₄₅	975.8
4	50 ₁₅₆	980.0	44 ₁₅₅	990.0	50 ₁₇₅	970.0	49 ₁₆₃	970.0	50 ₁₅₈	950.0	54 ₁₅₅	954.5	54 ₁₅₅	954.1	54 ₁₅₅	951.5
5	49 ₁₅₇	975.0	54 ₁₅₉	970.0	50 ₁₇₇	975.0	59 ₁₇₂	995.0	55 ₁₇₅	960.0	54 ₁₇₀	959.5	54 ₁₆₅	960.4	54 ₁₆₅	958.5
6	54 ₁₆₇	970.0	39 ₁₄₈	995.0	47 ₁₇₀	980.0	60 ₁₄₅	990.0	41 ₁₄₇	970.0	54 ₁₇₅	974.3	54 ₁₇₅	976.4	54 ₁₈₀	975.0
7	52 ₁₆₂	975.0	48 ₁₅₉	990.0	53 ₁₆₈	979.2	68 ₁₄₀	985.0	46 ₁₄₀	970.0	50 ₁₇₀	971.4	50 ₁₇₀	970.4	50 ₁₇₀	967.8
8	55 ₁₇₅	970.0	54 ₁₆₁	970.0	60 ₁₅₈	975.0	56 ₁₄₄	970.0	40 ₁₄₁	970.0	50 ₁₇₀	976.8	50 ₁₇₀	978.4	54 ₁₇₀	972.9
9	62 ₁₇₅	984.4	55 ₁₅₉	992.5	45 ₁₈₀	989.0	56 ₁₄₀	970.0	44 ₁₇₉	980.0	54 ₁₅₀	975.8	54 ₁₅₀	976.0	58 ₁₅₅	974.8
10	44 ₁₇₂	995.0	39 ₁₅₀	960.0	52 ₁₅₃	985.0	55 ₁₃₇	980.0	47 ₁₇₃	975.0	50 ₁₅₅	991.5	66 ₁₄₅	977.8	66 ₁₅₀	983.3
11	49 ₁₈₀	985.0	44 ₁₆₀	950.0	48 ₁₆₆	990.0	64 ₁₇₅	990.0	47 ₁₇₄	985.0	50 ₁₇₀	982.3	54 ₁₆₅	974.2	50 ₁₇₀	987.3
12	52 ₁₇₂	980.0	48 ₁₆₂	960.0	59 ₁₄₂	975.0	59 ₁₄₈	985.0	39 ₁₄₆	975.0	50 ₁₅₀	978.2	54 ₁₈₀	976.9	50 ₁₅₀	974.4
13	56 ₁₆₈	985.0	47 ₁₆₅	970.0	60 ₁₄₃	988.8	56 ₁₃₉	975.0	47 ₁₆₆	975.0	54 ₁₆₀	970.7	54 ₁₆₅	968.8	54 ₁₆₅	967.0
14	56 ₁₆₅	995.0	47 ₁₇₀	985.0	56 ₁₆₀	970.0	42 ₁₃₂	980.0	51 ₁₅₈	980.0	54 ₁₆₅	969.8	54 ₁₆₅	961.5	54 ₁₇₀	961.8
15	60 ₁₆₅	998.3	42 ₁₆₉	985.0	58 ₁₇₄	980.0	44 ₁₅₆	975.0	43 ₁₇₅	975.0	54 ₁₈₀	965.9	54 ₁₇₅	965.1	58 ₁₇₅	965.7
16	50 ₁₅₈	985.0	43 ₁₆₄	970.0	53 ₁₃₅	980.0	54 ₁₅₄	950.0	47 ₁₇₄	960.0	58 ₁₆₅	967.4	58 ₁₇₀	974.5	62 ₁₇₀	962.4
17	54 ₁₆₄	970.0	43 ₁₆₈	970.0	57 ₁₄₅	980.0	57 ₁₆₂	980.0	52 ₁₇₄	962.6	46 ₁₃₅	996.8	50 ₁₇₀	974.3	60 ₁₇₀	967.2
18	61 ₁₇₅	980.0	42 ₁₆₃	985.0	56 ₁₄₂	980.0	45 ₁₅₉	975.0	52 ₁₇₇	964.0	46 ₁₅₀	980.2	54 ₁₇₅	975.8	56 ₁₇₅	971.1
19	62 ₁₇₀	985.0	41 ₁₄₂	988.4	42 ₁₆₁	985.0	54 ₁₆₆	960.0	52 ₁₇₇	969.9	50 ₁₇₀	970.2	62 ₁₆₀	972.2	58 ₁₇₅	968.8
20	55 ₁₆₅	960.0	42 ₁₅₆	980.0	50 ₁₄₀	965.0	58 ₁₆₄	975.0	47 ₁₆₂	963.0	50 ₁₈₀	976.3	54 ₁₇₀	994.0	62 ₁₆₅	971.2
21	55 ₁₆₅	955.0	47 ₁₅₈	980.0	53 ₁₃₉	955.0	46 ₁₆₃	965.0	52 ₁₄₈	965.0	54 ₁₅₀	970.7	54 ₁₆₅	987.7	46 ₁₇₀	986.8
22	58 ₁₇₀	970.0	53 ₁₆₂	985.0	53 ₁₆₀	945.0	43 ₁₆₀	974.9	48 ₁₆₀	975.0	54 ₁₅₅	972.3	54 ₁₆₀	977.5	50 ₁₈₀	982.2
23	55 ₁₆₅	990.0	41 ₁₅₂	1007.0	56 ₁₇₄	975.0	46 ₁₅₆	970.0	41 ₁₆₀	965.0	58 ₁₇₀	970.9	54 ₁₇₅	973.0	54 ₁₅₅	967.1
24	52 ₁₆₉	985.0	48 ₁₅₈	995.0	51 ₁₅₇	980.0	47 ₁₅₉	970.0	49 ₁₆₄	965.0	58 ₁₅₀	981.9	58 ₁₈₀	973.0	54 ₁₆₀	966.0
25	56 ₁₇₀	990.0	37 ₁₇₃	1005.0	44 ₁₆₄	990.0	51 ₁₅₂	971.9	55 ₁₆₄	975.0	54 ₁₇₀	981.1	58 ₁₆₅	978.2	58 ₁₅₀	973.7
26	38 ₁₅₅	985.0	39 ₁₇₉	1000.0	52 ₁₆₃	985.0	47 ₁₅₃	975.0	49 ₁₅₄	985.0	54 ₁₇₀	974.5	58 ₁₆₀	973.4	54 ₁₅₀	977.3
27	50 ₁₆₇	975.0	38 ₁₇₃	1005.0	39 ₁₇₆	975.0	47 ₁₆₈	974.8	42 ₁₆₁	985.0	54 ₁₆₅	978.5	54 ₁₇₀	975.9	54 ₁₅₀	977.3
28	54 ₁₇₅	950.0	48 ₁₄₈	1000.0	46 ₁₆₄	965.0	47 ₁₇₈	975.0	45 ₁₇₅	985.0	58 ₁₆₀	980.3	58 ₁₈₀	975.3	54 ₁₇₀	970.8
29	58 ₁₆₈	970.0	55 ₁₅₅	990.0	49 ₁₇₂	960.0	48 ₁₇₀	972.0	42 ₁₆₇	955.0	54 ₁₆₀	980.6	58 ₁₈₀	977.9	54 ₁₈₀	968.7
30	62 ₁₆₆	975.0	41 ₁₇₀	995.0	49 ₁₅₈	970.0	56 ₁₄₂	975.0	47 ₁₆₀	970.0	58 ₁₆₀	981.4	58 ₁₅₀	980.8	58 ₁₇₀	968.6
31	43 ₁₆₃	995.0	45 ₁₄₅	980.0	55 ₁₆₀	988.3	59 ₁₄₆	978.0	46 ₁₇₄	970.0	54 ₁₆₅	981.3	-	-	-	-
Range	950.0-998.3		950.0-1005.0		945.0-990.0		950.0-995.0		950.0-985.0		954.5-996.8		954.1-994.0		951.5-987.3	
Mean	976.9		982.2		973.8		973.5		968.6		973.95		974.2		971.2	
Standard Deviation	11.7		13.7		10.4		8.8		8.7		7.42		7.31		7.58	
Mean Lat	53.4N		46.0N		51.0N		53.2N		47.1N		50.7N		55.2N		55.4N	
Mean Lon	175.3E		165.0E		171.8W		167.0W		172.4W		173.4E		176.0E		174.4E	

^aLat = Latitude, Lon = Longitude, (minus = west).

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